Design of a wireless multisensory data logger for operating room environments

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Abstract: *A system was designed to acquire experimental data from custom sensors in a conventional operating room. Available clinical equipment is usually incapable of reading out such experimental sensor systems and/or handling the resulting data stream. The proposed system integrates these prototype sensors and provides a data-alignment method based on ECG measurements on the different systems. The data logger is designed to work wirelessly in order to prevent cables cluttering the work environment and hindering the operating personnel. Multiple types of analog and digital sensors can be read out synchronously at high data rates. A graphical user interface (GUI) was designed that interfaces with existing software to mark events during the operation.*

Keywords: data acquisition, sensor readout, medical telemetry, operating room, accelerometer

1. INTRODUCTION

In medical research fields, experimental physicians might require the use of new types of electronic sensors, while working in a conventional operating room, using most of the regular equipment. An important requirement when using these new sensors (accelerometers, gyroscopes, pressure sensors, chemical sensors, mechanical sensors, …) is that the measurements can be synchronized in the time domain with conventional running measurements from the medical data loggers. Examples of such data are ECG, blood pressure, breathing, oxygen levels, ultrasound echography,… The time-synchronization is needed for later data analysis. The existing data logger systems in the operating room are not designed to be expanded with custom sensors and are usually closed systems, not permitting any modifications. Hence, there is need for a data logger system that combines these measurements in an easy and convenient way. The design of this system was performed in consultation with physicians planning to use the system and is explained in section 2. It was then tested in a measurement setup where accelerometers were used to determine the cardiac contractility of several sheep. These results are reported in section 3.

2. DESIGN AND IMPLEMENTATION

2.1 Electronics design

The electronics consist of two separate parts, one on the operating table, connected to the patient and the sensors, and another receiving the data and transmitting it to a personal computer. The two parts of the data logger are connected through a wireless RF link in order to keep the cables from obstructing the operating table. The design is depicted as a schematic in Fig.1.

The data logger located on or near the subject, called *patient board*, is powered by a battery, again to avoid the use of cables and to guarantee the safety of the subject. It consists of a microcontroller, connected to several peripherals. The microcontroller chosen is Texas Instruments CC430F5137. The main reason for this choice is support for some useful properties: mapping any peripheral functionality to any IO pin, dynamic

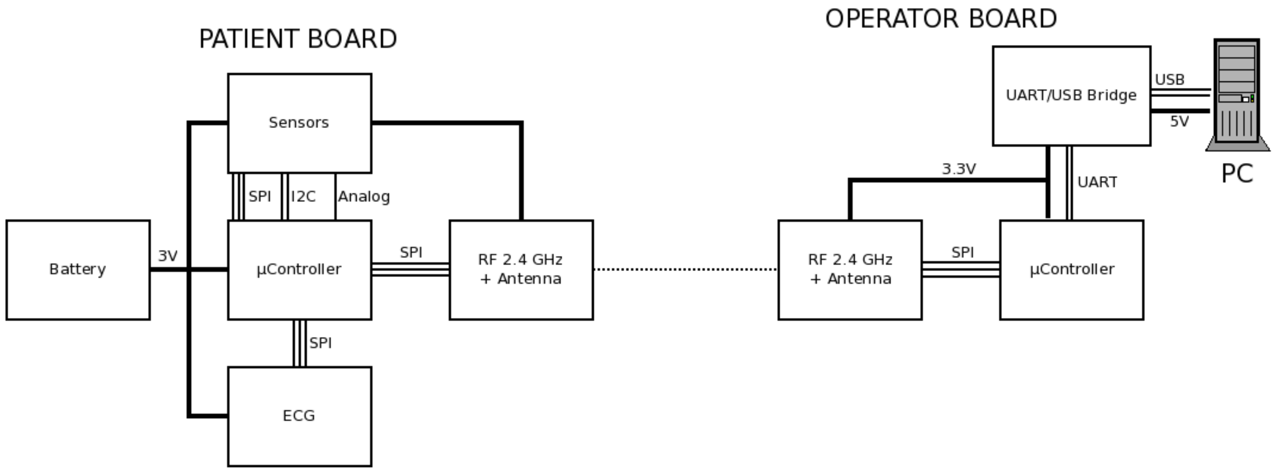

Fig. 1 Block diagram of the system. On the left the board that is placed near the subject, on the right the operator board providing a connection to a computer for data storage and analysis.

remapping of these pins during the execution of the software, integrated wireless communication over the 433 MHz ISM band and simultaneous use of the SPI and I^2C bus. The microcontroller is capable of reading a large number of digital sensors through the SPI and I^2C bus, while the integrated ADC can be used for reading out analog sensors. The patient board is designed in a modular fashion, a central board with several places to connect modules, allowing for a flexible range of setups. Due to the possible requirement of high sample rate, the internal 433 MHz RF transceiver can be replaced by an external high-speed wireless link (e.g. Nordic nRF24L01+). All sampled data is sent over the wireless link to the second board, called *operator board*. Fig.2 depicts the modular patient board after assembly for measurement.

The operator board (Fig.3) is located near a personal computer (PC) operated by a person from medical staff. It has the same microcontroller, matching RF communication and is connected to a PC. The computer provides power and data to the board, and can save and plot the data sent over the serial port.

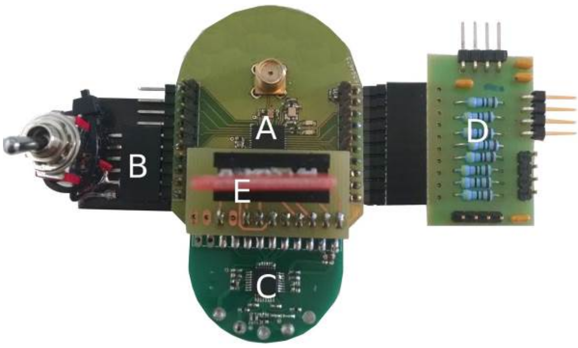

Fig. 2 The modular patient board, consisting of (A) microprocessor, (B) battery, (C) ECG circuit, (D) sensor connector, (E) RF module and antenna.

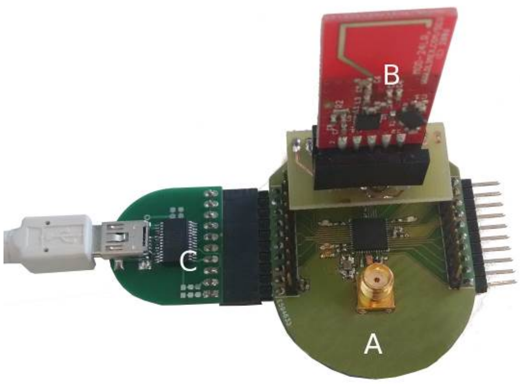

Fig. 3 The operator board, consisting of (A) microprocessor, (B) RF module and antenna, (C) UART/USB bridge

2.2 Synchronization of data

Post-operation data analysis requires all data streams, from the custom sensor data logger and the medical machinery, to be synchronized in time. The synchronization allows the result of different events, such as administration of medication or changes in the physical environment, to be seen and the impact to be analyzed. One method to do the alignment of the different data streams, is the use of very precise timestamps that are saved for each data sample. However, this requires very precise real-time clocks, accurate to the order of milliseconds, which is not the case in personal computers. The method used in this work to align both signals very accurately in time, is to make dedicated alignment marks in both datasets, and refining the synchronization by logging an auxiliary signal.

The alignment marks provide a rough signal alignment in the order of a few seconds. The refinement of synchronization is then performed by comparing identical signals measured by different data loggers. For this purpose, a system was designed using electrocardiography (ECG) acquisition on every separate data logger, since most medical equipment already has this functionality. The ECG signal can then be used to do the accurate alignment of data in time, by comparing and finding the correct corresponding QRS-complexes. This can be done manually or by using an autocorrelation.

The data logger is therefore expanded with an analog front-end for ECG (Texas Instruments ADS1292). The electrodes of this module are to connected at the same locations as the other equipment to measure the same signal.

2.3 Firmware design

The firmware running on the data logger is a simple program written in C that performs a digital readout of the sensors. Unlike the medical data logger designed in [1], the system does not need a EEPROM memory to store data or a real-time clock, which simplifies the design process. The TI ADS1292 chip includes a programmable interrupt that runs on an integrated timer. This interrupt is set to the required data rate and can be used for the other sensors as well. If different data rates are required, the microcontroller supports the use of timers. After reading the correct amount of data, the firmware wirelessly transfers the data in packets of 32 bytes. If the nRF24L01+ link is used, there is included support for retransmission of failed data.

In order to have a large degree of autonomy for the medical staff, the patient board has several LEDs to indicate status of the sensors and the status of the wireless transmission.

3. MEASUREMENT AND RESULTS

3.1 Introduction and setup

Heart diseases and anomalies can often manifest in a change of contractility of the heart, i.e. strength of the heart muscle to pump blood. Measuring the contractility can therefore be useful as a means of assessing the healthiness of the heart. In an attempt to learn more about local contractility differences and heart wall movements, a custom measurement system was needed.

Contractility is conventionally measured through the rate of blood pressure change dP/dt during isovolumetric contraction. The pressure sensors required make these measurement devices quite invasive and bulky. Recent developments during the last decade in miniaturization of microelectromechanical systems (MEMS) bring the possibility to use different types of sensors that will drastically decrease size and weight of these measuring devices. For example, a 3-axis accelerometer can be used to assess dynamic movement of the heart wall and peak acceleration has been shown to correlate well to conventional dP/dt measurements [2]. The designed system was tested during acute measurements on the cardiac muscle of several sheep.

Up to four 3-axis accelerometers (Bosch Sensortec BMA280) were connected and sampled at 250 Hz, along with the ECG signal at the same data rate. The high data rate and number of sensors was the primary reason to implement RF communication over the 2.4 GHz link replacing the internal 433 MHz transceiver.

The endocardial accelerometers, depicted in Fig.4, are punctured through the heart wall and implanted during acute tests. They are covered by a custom designed biocompatible packaging process described in [3]. The ECG system is connected to the sheep with a positive and negative lead across the chest and one right-leg drive electrode, connected in the same locations as the other ECG systems through crocodile clamps. A picture of the setup installed on the animal is given in Fig.5.

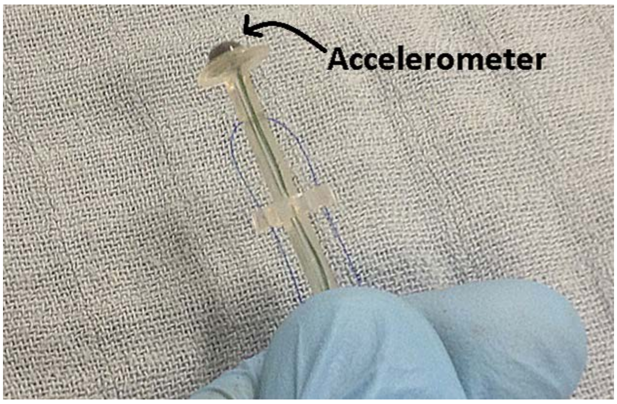

Fig. 4 The accelerometer is packaged on a rod for insertion through the heart wall, and is covered by a biocompatible coating.

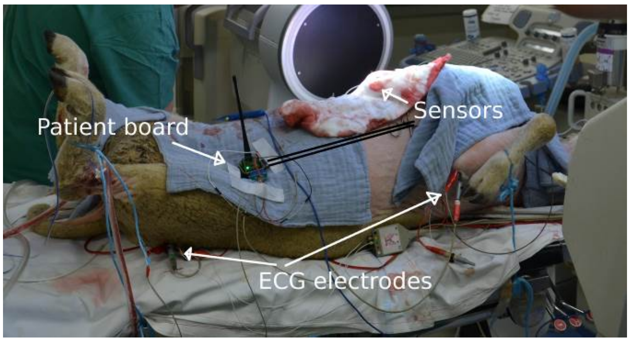

Fig. 5 The measurement setup for cardiac contractility. The test animal is positioned on the operating table. The patient board is located on the animal, connected to 4 accelerometers and 3 ECG electrodes (third one behind the animal). In this picture an antenna for 433 MHz is used.

3.2 Software and user interface

A personal computer in the operating room is running the ADInstruments LabChart software to control the existing medical equipment and visualize data through a scrolling plot. During the separate measurement tests, the operator of this software is controlling several aspects of the graphical user interface, such as pressing buttons to mark events, annotate comments and start and stop the acquisition. In order to get clean and easy to process datasets, generally a fast response time is needed, which makes it difficult to control a second acquisition software at the same time.

The custom data logger system delivers data over UART through a USB bridge (FTDI FT232R) to the same personal computer. The serial data stream can be read by any software the designer desires. An working example was constructed using the MathWorks MATLAB software. The program collects the data for visualization and storage. A graphical user interface was designed to show a live plot of the accelerometer and ECG data. There are control buttons for annotating special events (administration of medication, pacemaker parameters, …) and for starting and stopping the acquisition of data. A short sample of the received data is shown in Fig.6.

In order to also use the MATLAB software on the same computer, an interface was designed between both

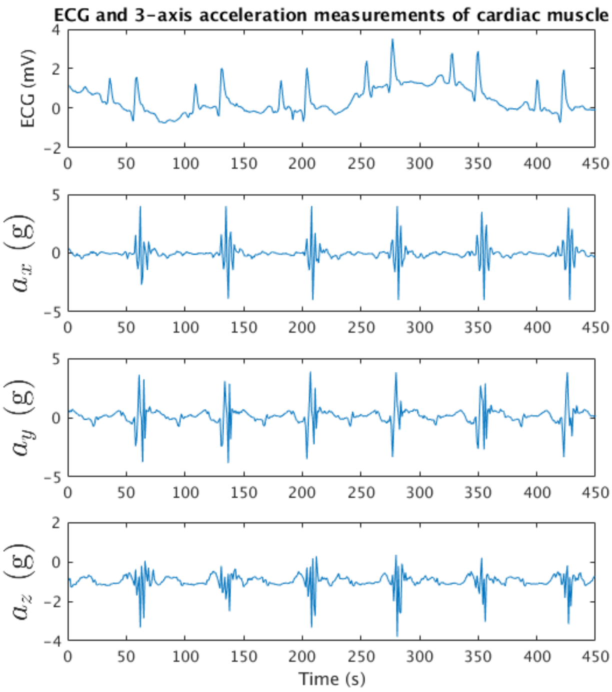

Fig. 6 Measurements of the ECG sensor and one of the accelerometers (axis x, y and z).

programs so that the same person from medical staff can operate both at the same time. The LabChart software supports an interface that allows control by other programs. It is running a COM server which can be accessed by MATLAB via a COM interface. The buttons in the MATLAB software execute control functions for the accelerometer acquisition and emulate the button presses in the LabChart software at the same time. This way, the operator is effectively controlling both programs simultaneously. With a single click, special events can be marked in both datasets, providing the rough dataset alignment.

4. CONCLUSIONS

A data logger system was designed and fabricated, tailored to a specific demand for custom sensor readout amidst medical equipment in an operating room, but easily generalized and useable for other measurements. It was successfully used during acute measurements on the cardiac muscle of sheep. The data logger supports readout of any digital sensor with SPI or I^2C interface, as well as analog sensors.

A custom method for data-alignment via ECG signals was included, to make later data analysis more accessible for the researchers. The accompanying custom software was optimized for easy operation during the surgery by interfacing with the control software of the existing equipment.

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